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PHOTOPRODUCTION OF INTERMEDIATE VECTOR BOSONS

M. BANDER †

Institute for Theoretical Physics, University of Copenhagen, Denmark

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Abstract: A peripheral collision calculation of the process $\gamma+p \rightarrow W+\ldots$, where W is an intermediate vector boson, is performed. Results and possible detection schemes are discussed.

1. Introduction

The recent experimental verification of the two-neutrino hypothesis [1]) adds further strength to the idea that weak interactions are brought about as a second order effect of a more fundamental process where an intermediate boson W of spin one is exchanged. There will now follow attempts actually to produce such a boson. Any such experiment meets with two difficulties: (1) the cross section is extremely small; (2) the lifetime of such a boson is too short for it to be actually observed and distinguished from a possibly large background.

Several schemes have been suggested for the production of this particle. The original one involves the use of high energy neutrinos [2]). There is also a proposal to produce it by scattering pions on nucleons [3]). In this article we shall investigate the feasibility of photoproducing them. At present and more likely in the near future high energy electron accelerators will be available to give the necessary high energy photons. In sect. 2 we discuss the calculation of the cross section for this process, and in sect. 3 we consider possible means of detection if such a particle is produced.

2. Cross-Section Calculation

2.1. PERIPHERAL GRAPHS

We consider the process $\gamma+p \rightarrow W^{+}+\ldots$ (the results for W^{-} are qualitatively and quantitatively very similar), and calculate it in a peripheral collision approximation. The first graph we study is the one for a two-particle final state, i.e. $\gamma+p \rightarrow W^{+}+n$ (fig. 1). We also look at the case where there are more particles in the final state, such as π, K, $\bar{\text{K}}$ mesons. The peripheral graphs are indicated in fig. 2. We shall now give an argument to show that the major contribution is from graph 2a. As was shown by Drell [4]) for high energy photo-pion production, such processes favour graphs in which at the upper vertex (fig. 2) the photon is annihilated and *one* high energy

† National Science Foundation Postdoctoral Fellow.

particle is produced. In this case the momentum of the virtual pion lies nearest to the pole. This excludes graphs 2c, d. In graph 2b, where a pion is produced at the upper vertex and the W boson in the virtual pion-proton collision, we notice that the pion

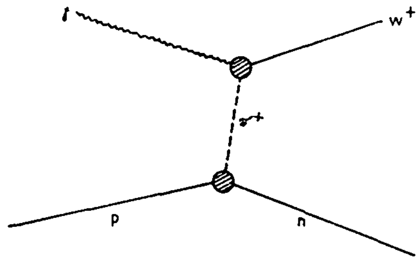

Fig. 1. Peripheral graph for $\gamma+p \to n+W^+$.

will tend to carry most of the energy, and there will be little left for producing the W boson, which we assume to be much more massive than the pion. On the other hand, in graph 2a, the production of a few low energy pions will not lower the energy

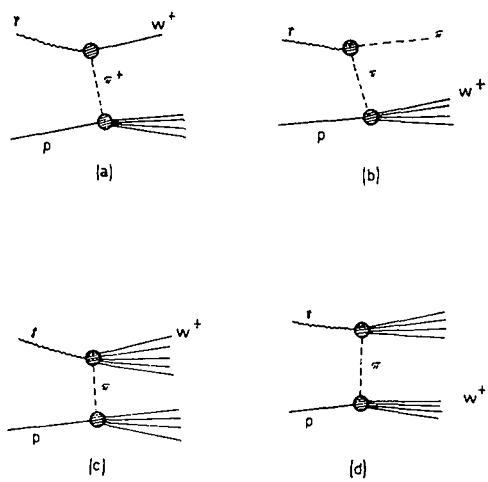

Fig. 2. Peripheral graphs for $\gamma+p \to W^{+}+\ldots$.

of the massive W boson to any large extent. Briefly the argument states that graph 2a is the only possible one in which we can both produce a W boson and have a high energy particle leaving from the upper vertex. The reason we are at all interested in the process where more than just the W boson is produced is that such a graph contributes much more than the one of fig. 1, due to the fact that one is not limited by the γ_5 interaction of the pπp vertex, but may put in the total experimental π-p cross section. It will turn out that graph 2a is at least ten times more important than the graph of fig. 1, and at high energies almost the entire process comes from this graph.

2.2. γ-W-π VERTEX

In both fig. 1 and fig. 2a we notice that we have at the upper vertex the interaction γ-W-π. We determine the form of this vertex by an extension of the principle of minimum electromagnetic coupling, i.e. we assume some Lagrangian not involving the photon field and replace all derivatives of charged fields by appropriate gauge invariant operators ($\partial_\mu \to \partial_\mu \pm ieA_\mu$). From Lorentz and gauge invariances we

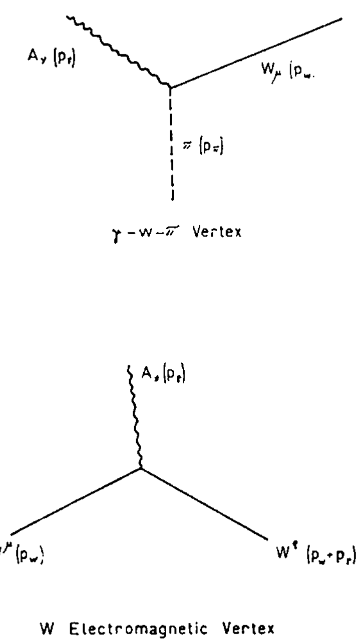

Fig. 3. Electromagnetic vertices.

deduce that the γ-W-π vertex (fig. 3), for real γ ray and W boson, must be of the form

$$G(p_\pi^2)[g^{\mu\nu} p_W p_\gamma - p_W^\nu p_\gamma^\mu],$$

where G is some arbitrary form factor. From the observed $\pi \to \mu + \nu$ decay we know that there must exist a π-W interaction which we take to be local of the form

$$\lambda W^\mu \partial_\mu \pi.$$

(The symbols designate both the particle and the field operator which annihilates it.) From the knowledge of the $\pi \to \mu + \nu$ rate we may compute λ. Also as the electromagnetic vertex of W we take (fig. 3)

$$e\{-g^{\mu\rho}(2p_{\mathrm{W}}+p_{\gamma})^{\nu}+(1+K)[p_{\mathrm{W}}^{\rho}g^{\mu\nu}+(p_{\mathrm{W}}+p_{\gamma})^{\mu}g^{\rho\nu}]-K[p_{\mathrm{W}}^{\mu}g^{\rho\nu}+(p_{\mathrm{W}}+p_{\gamma})^{\rho}g^{\mu\nu}]\},$$

where $1+K$ is the total magnetic moment of the boson. Performing the gauge invariant substitution discussed above we obtain for G the expression

$$G = -\frac{\lambda e}{M_{\mathrm{W}}^2}(1-K),$$

where M_{W} is the boson mass.

2.3. CROSS SECTION

We use units $\hbar = c =$ mass of nucleon $= 1$. The cross section due to graph 1 is

$$\sigma = \int \frac{1}{16(1+\nu)^2}\frac{f^2}{\mu^2}\frac{G^2F(\Delta^2)\Delta^2(\Delta^2+M_{\mathrm{W}}^2)^2}{(\Delta^2+\mu^2)^2}\,\mathrm{d}(\Delta^2),$$

where Δ is the momentum squared of the virtual pion, ν is the total centre-of-mass energy squared, $f = 0.08$ and $F(\Delta^2)$ is a cut off on the momentum integration which represents the collective form factor of the pion propagator and both vertices. In analogy with other peripheral collision calculations [5]) we use for F the form

$$F = \frac{K^4}{(\Delta^2+K^2+\mu^2)^2}$$

with $K^2 \approx 50\mu^2$.

The cross section due to graph 2a is

$$\iint \frac{G^2F(\Delta^2)(v+1-\Delta^2)}{16(2\pi)^2(1+\nu)^2(\Delta^2+\mu^2)^2}(\Delta^2+M_{\mathrm{W}}^2)^2\sigma(v)\mathrm{d}v\,\mathrm{d}(\Delta^2),$$

where v is the centre-of-mass energy squared of the virtual pion and target nucleon, and $\sigma(v)$ the total π-n scattering cross section [6]).

3. Results

The cross section is presented for $M_{\mathrm{W}} = 1$ and $K = 0$. The results are plotted in figs. 4 and 5. As mentioned previously the graph of fig. 2a dominates that of fig. 1. The cross section increases logarithmically with energy and for incident energies less than 10 GeV is of the order of 10^{-36} cm^2. This makes it 10^{-5} to 10^{-6} of the total photo-nucleon cross section, which makes the detection of the W boson very difficult. We shall discuss a possible signature for such an event which might make it feasible to extract it from the background.

To do this we notice, as was expected before, that the W boson likes to take up as much energy as possible. This is indicated in fig. 6. In fact the most likely process will be $\gamma+\mathrm{p} \rightarrow \mathrm{W}+\mathrm{n}+\pi$ where the n-π system comes off near the 3-3 resonance. The signature of such an event will then depend on the decay mode of the W boson.

If the decay mode is leptonic, there is the difficulty due to Compton scattering on electrons in any scattering material. However, we should only look at events in which

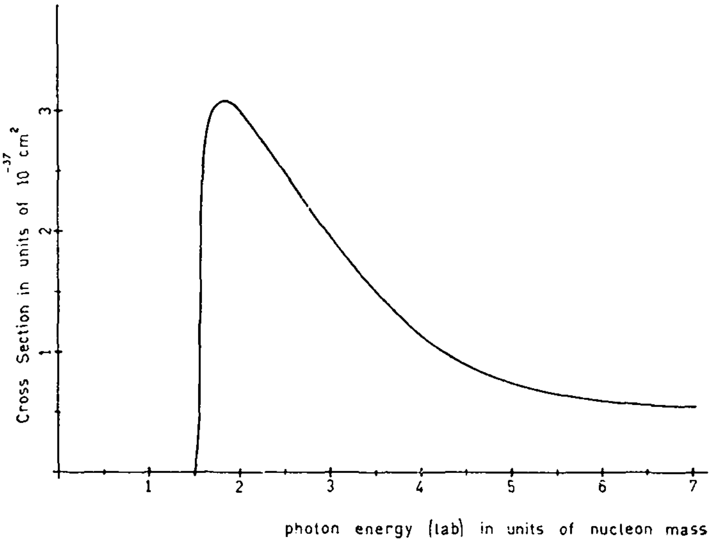

Fig. 4. Cross section for $\gamma+p \rightarrow n+W^+$ for $M_W = 1$, $K = 0$.

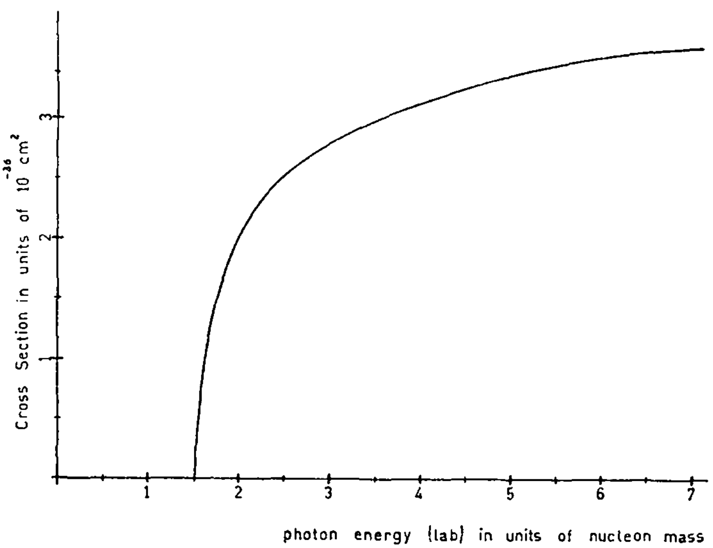

Fig. 5. Cross section for $\gamma+p \rightarrow W^+ + \ldots$ for $M_W = 1$, $K = 0$.

there emerge one high energy lepton and at least one low energy pion. As about half the W leptonic decay mode will be into μ mesons, we should also look for higher energy muons and low energy pions.

If the decay is predominantly pionic, the detection becomes much more difficult. We would be looking for events with, say, two high energy pions and a low energy pion. However, this would look very much like a π-π resonance. This point has been already discussed by Bernstein and Feinberg [3]). The only hope at present to detect the W boson via this production will be if it decays leptonically, where the above

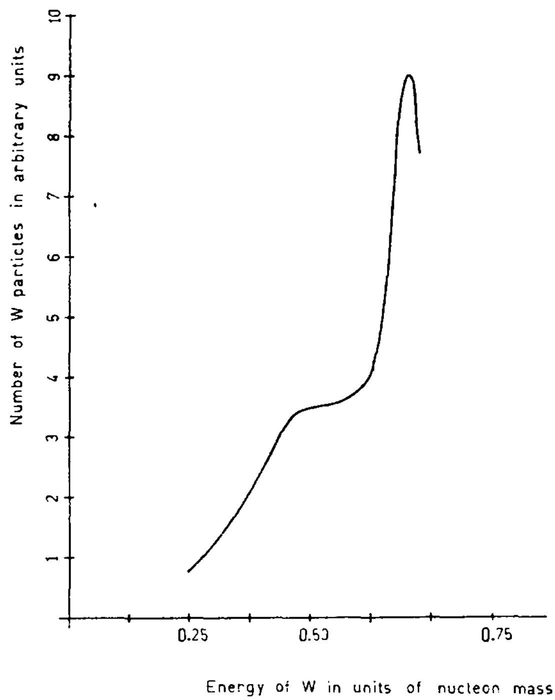

Fig. 6. Recoil spectrum for W^+ for incident energy of 2 nuclear masses.

criteria may reduce the number of events which require closer study to manageable proportions.

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